

# Large Area $\text{YBa}_2\text{Cu}_3\text{O}_{7-x}$ Bolometers on Si Substrates

L. R. Vale and R. H. Ono,  
National Institute of Standards and Technology, Boulder, CO 80303

D. G. McDonald and R. J. Phelan,  
Boulder Metric, Inc. Boulder, CO 80303

**Abstract**—We have developed  $\text{YBa}_2\text{Cu}_3\text{O}_{7-x}$  (YBCO) thermometers for large area (4 mm x 4mm) electrical substitution bolometers. We passivated the YBCO with a thin Au layer and demonstrated a noise equivalent temperature (NET) of 4 nK  $\text{Hz}^{-1/2}$ . We then used a resistor layer of NiCr alloy deposited directly on the thermometer to perform optical measurements of the bolometer in the cryostat. Optical measurements show an electrical noise equivalent power (NEP) of 87 pW  $\text{Hz}^{-1/2}$  with a large thermal conductance of  $1.87 \times 10^{-3} \text{ W/K}$ . These thermometers may be used as a real-time measurement radiometer.

## I. INTRODUCTION

We report on the fabrication of a high temperature superconducting (HTS) bolometer for a radiometer operating at liquid nitrogen temperature that can be used in the infrared, visible, and ultraviolet regions of the electromagnetic spectrum. The application of this bolometer requires a large thermal conductance combined with low noise. The sensitivity of the bolometer depends on the thermal conductance  $G$  to the reservoir and the noise of the thermometer. Our goal was an electrical noise equivalent power (NEP) of 100 pW  $\text{Hz}^{-1/2}$  at a chopper frequency of 10 Hz.

Our composite bolometer consists of a (4 mm)<sup>2</sup> membrane of Silicon (Si), with YBCO and buffer-layer thin films grown by pulsed-laser deposition, and a thin film heater which will be used for calibration by the electrical substitution-of-power method. The large area membrane detector is unique for calibrated HTS radiometers because of the large  $G$  and simultaneously low noise temperature. We will discuss the fabrication issues which presented the greatest challenges to successful device performance: achieving thermal isolation of the detector by Si back etching, uniform strain-free deposition of large area YBCO films on Si, and electrical isolation of the large area detector from the heater.

## II. FABRICATION

The YBCO is grown to a maximum thickness of 50 nm to minimize the mechanical stress inherent in YBCO grown on Si. Previous studies have shown the sensitivity to environmental degradation of YBCO films on Si, due to stress induced by differential thermal expansion [1]. This is seen as a decrease in the film's critical temperature and current den-

sity. We have previously demonstrated low noise in large area YBCO devices on Si [2]. However, we have observed that standard photolithographic processing can deteriorate these devices and result in an anomalous increase in voltage noise of current-biased YBCO devices on Si. Our application required further processing and a need to insulate the YBCO from the subsequent heater layer.

The vertical structure of the devices we fabricated is shown in Fig. 1. The bolometer fabrication begins with a B-doped Si substrate upon which we deposit 200 nm of epitaxial yttria-stabilized zirconia (YSZ) and 20 nm  $\text{CeO}_2$  (CeO) as buffer layers to prevent interaction between the Si and the YBCO film (Fig. 1a). The fabricated thermometer would then be followed by the deposition and fabrication of a heater layer, which would be electrically isolated from the YBCO thermometer. The need for passivation with long term stability and for electrical isolation for the YBCO, resulted in an investigation of a variety of insulator layers. We worked with room-temperature grown amorphous films and epitaxial *in situ* films of yttria stabilized zirconia and CeO to protect the YBCO. Unfortunately, the amorphous films themselves were easily damaged and not pinhole-free, thus not able to protect the underlying YBCO from subsequent patterning effects. We then developed a process (based on a passivation process that we use successfully on YBCO films on substrates other than Si [3]) for depositing *in situ* epitaxial passivating  $\text{SrTiO}_3$  (STO) films using a mechanical mask that also allowed for the deposition of *in situ* Au contacts. Unfortunately, the STO layer made it difficult to fully oxygenate the underlying YBCO on Si and resulted in thermometer devices demonstrating a higher noise level.

Our previous studies on long term stability of passivated vs. non-passivated Josephson junctions using Au normal metal layers [3] plus other studies on the use of Ag on YBCO for passivation [4,5] encouraged us to try this technique for the 50 nm YBCO films on Si. We followed the YBCO deposition with an *in situ* layer of 20 nm thick Au deposited by sputtering at 100 °C (Fig. 1b). This Au layer does cause an electrical shunt to the YBCO, but it is resistant to processing effects and has the added benefit of providing *in situ* contacts for the voltage and current leads. Passivation of the YBCO was confirmed with measurements of the noise equivalent temperature (NET) of the thermometer, before and after processing, which remained unchanged. Another added benefit of this *in situ* Au passivation technique is its effect on the thermometer NET which appears to be the lowest value yet

\*Contribution of the U.S. Government and not subject to copyright.

reported for a device of this type and is of order  $4 \text{ nK Hz}^{-1/2}$  [5].

With the passivation and long term stability of the YBCO achieved, we now required electrical isolation of the thermometer from the electrical substitution heater. We

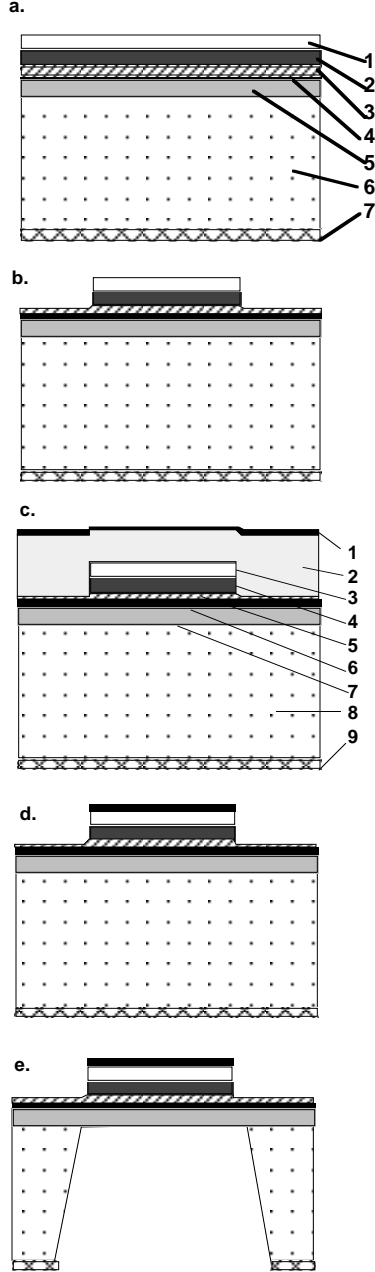


Fig. 1. Vertical structure and fabrication sequence. (a) The layer sequence grown in situ is: 1- Au, 2-YBCO, 3-CeO, 4-YSZ, 5-Boron doped Si, 6-Si (100), and 7-SiO<sub>2</sub>. (b) shows the structure after patterning the thermometer (Au/YBCO). (c) shows the sequence with a deposited insulator and heater/absorber: 1-NiCr or AuPd, 2-DPXN, 3-Au, 4-YBCO, 5-CeO, 6-YSZ, 7-B-Si, 8-Si, and 9-SiO<sub>2</sub>. (d) shows the use of a directly grown absorber layer and (e) shows the result after membrane etching.

tested a number of different spin-on and vapor deposited polymer films, as well as evaporated or pulsed laser deposited materials. We used a vapor deposition polymerization process of Polyparaxylylene (DPXN) because of its excellent insulating qualities (Fig. 1c). NiCr or AuPd heater layers, seen as the meander line in Fig. 2, were patterned by liftoff on these polymer films. Subsequent processing included KOH etching of the back side of the Si (for 2.5 hours) to produce the  $2.8 \mu\text{m}$  B-Si supporting membrane (Fig. 1e) that we required for our high conductance, high speed bolometer. The  $0.5 \mu\text{m}$ - $1 \mu\text{m}$  thick layers of DPXN material resulted in a mechanical strain that ruptured the  $2.8 \mu\text{m}$  thick B-Si when the membrane was cooled to liquid nitrogen temperatures for testing. The trade-off between perfect electrical isolation and mechanical strain with thick insulator films over the relatively large  $4 \text{ mm} \times 4 \text{ mm}$  area required for the calibration heater remains problematic. Alternatively, we deposited a  $12 \text{ nm}$  thick absorbing NiCr layer directly on the normal-metal passivated YBCO thermometer (Fig. 1d), which allowed us to make optical measurements to verify the properties of the bolometer. The completed bolometer (Fig. 2), which was thermally isolated on the  $2.8 \mu\text{m}$  thick B-doped membrane, was mounted in the cryostat and measured.

### III. RESULTS

The bolometer described here, with the NiCr absorber, was measured in the cryostat using a  $670 \text{ nm}$  wavelength power-stabilized diode laser scanned over the entire thermometer area. With a time constant of  $16.8 \text{ ms}$ , this device had an optical NEP of  $87 \text{ pW Hz}^{-1/2}$  which is notably small for a device with a large thermal conductance of  $1.87 \times 10^{-3} \text{ W/K}$ ,

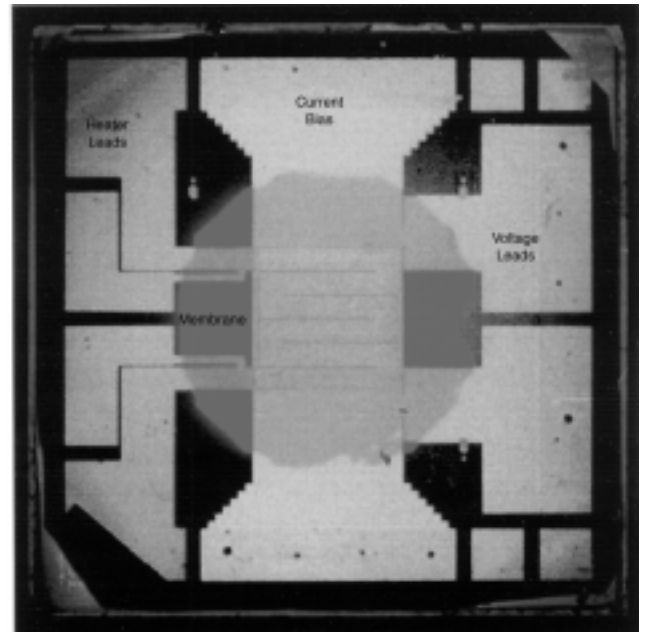


Fig. 2. Photograph of the completed bolometer chip which is  $14 \text{ mm}$  on a side.

and exceeded our intended goal of  $100 \text{ pW Hz}^{-1/2}$ . The specifics of the measurement technique and recorded data table are reported in detail in Ref. [6]. We have demonstrated the combination of a large thermal conductance with an excellent low noise thermometer that provides for a large dynamic range radiometer.

#### IV. CONCLUSIONS

The bolometer is notable for its combination of low noise and large thermal conductance. Further work is needed to optimize insulator thickness and reduce mechanical strain on the membranes, these improvements would allow the fabrication of the electrical substitution heater that is necessary for calibration of the bolometer. The thermometer performance is sufficiently encouraging that we plan to fabricate these devices using Si-on-insulator (SOI) substrates. We can then take advantage of the demonstrated low noise and improve the NEP by reducing the thermal conductance. The resulting loss

of speed can be compensated by negative electrothermal feedback. The resulting bolometer can then be used in more generic applications of long-wavelength infrared detectors.

#### REFERENCES

- [1] H. Brehner, K. Ruhrschopf, G. Wedler, and W. Rauch, "Surface reactions and long time stability of YBCO thin films," *Physica C* 208, pp. 419-424, 1993
- [2] D.G. McDonald, R. J. Phelan, L.R. Vale, R.H. Ono, J.P. Rice, et al, "Noise from YBCO films: Size and Substrate Dependence," *IEEE Trans. Appl. Supercond.* 7, pp. 3091-3095, 1997.
- [3] L.R. Vale, R.H. Ono, and D.A. Rudman, "YBCO Josephson Junctions on Bicrystal  $\text{Al}_2\text{O}_3$  and STO Substrates," *IEEE Trans. Appl. Supercond.* 7, pp. 3193-3196, 1997.
- [4] C.A. Chang, "Effects of Ag and Au on the YBCO superconducting thin films with the use of Ag/Cu/BaO/ $\text{Y}_2\text{O}_3$  structures," *Appl. Phys. Lett.* 52, pp. 924-926, 1988.
- [5] C.A. Chang, "Reduced moisture induced degradation of YBCO films by silver and high deposition temperatures," *Appl. Phys. Lett.* 53, pp. 1113-1115, 1988.
- [6] D.G. McDonald, R. J. Phelan, L.R. Vale, R.H. Ono, and D.A. Rudman, "Passivation, Transition Width and Noise for YBCO Bolometers on Si," to be published in *IEEE Trans. Appl. Supercond.*, 1999.